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Risk Assessment of Asian Clam Invasion in Lake Champlain

Executive Summary

This report encompasses the effects of the invasive species *Corbicula fluminea,* commonly known as the Asian clam, on water bodies in North America. The purpose of this assessment is to infer their potential effects on Lake Champlain. Studying the impacts of the Asian clam on Lake Tahoe and Lake George helped us to determine what may occur in Lake Champlain if the Asian clam invades. This comparison is useful as the climate of Lake George is similar to that of Lake Champlain, while the effects of the clam have been studied at greater length in Lake Tahoe.

The invasion of *Corbicula fluminea* would negatively affect the water quality of Lake Champlain. Negative impacts include changes to water chemistry, nutrient loading, nuisance algae blooms, and damage to fisheries. These changes in water quality would affect recreation, community programs, and the property values of Lake Champlain communities.

The effectiveness of various control mechanisms will also be assessed in this report. If *Corbicula fluminea* were to invade Lake Champlain, our key recommendation would be a rapid response. Any hesitation could potentially cause the invasion to spread beyond our capacity to control, as was the case in Lake Tahoe. By following the procedures that Lake George has enacted, the invasion can be contained rapidly. Ideally, these procedures would be directed by the Lake Champlain Basin Program Aquatic Invasive Species Task Force (LCBPAISTF). By acting rapidly, the risk posed by *Corbicula fluminea* can be minimized.

Problem Statement

Corbicula fluminea, commonly referred to as the Asian clam, is known for its ability to invade aquatic systems. They are aggressive competitors and reproduce rapidly, which contributes to a loss of biodiversity in ecosystems. In large numbers, they have the capacity to dramatically alter water chemistry by excreting nitrogen and phosphorus, which facilitates nuisance algal blooms (Zhang, 2011).

The Asian clams are an aesthetic and economic concern as well. Shells provide a substrate for zebra mussels and can wash up on shore, ruining the functionality of recreational beaches (Wittmann, 2008). The increased algal blooms drive tourist dollars from the area and further reduce the recreational utility of the lake. Lastly, clam-driven reductions in fish populations threaten to reduce revenue from sports fishing. On the brink of entering Lake Champlain, the arrival of the Asian clam would have severe impacts on the economy and ecology of the lake.

Justification

Asian clams are known for their capacity to invade and out-compete native bivalve species. They are able to survive in a wide range of temperatures and can tolerate pH values as low as 5.6 if other environmental conditions are satisfied (Wittmann, 2008). While *C. fluminea* was first believed to be intolerant of temperatures below 2 degrees Celsius, their established population in Lake George seems to indicate otherwise (Wittmann, 2008).

With the ability to self-fertilize, Asian clams reproduce at least 2 times a season and their larvae are highly mobile. With the aid of mucous threads these larvae can remain suspended in the water column and disperse over long distances using the water currents. The number of larvae produced per individual reproductive cycle seems to have a large variance between ecosystems. In Lake Tahoe, the average number of offspring produced was in the realm of 68,000 larvae (Wittmann, 2008). The Lake George Asian Clam Rapid Response Task Force (LGACRRTF) indicates 2,000 to 4,000 larvae are produced per cycle. These differences indicate that despite their tolerance for a variety of environmental conditions, the productivity of the Asian clams is still greatly affected by the physical and chemical properties of the waters they inhabit. This alone is justification for further study of the effects of environmental conditions on the Asian clam's productivity.

Asian clams secrete biologically available nitrogen and soluble phosphorus into their environment. This may be true of all bivalves, but the overwhelming density of an established *C. fluminea* population (>3000 individuals per square meter for a small population) dwarfs the contributions of other species (See Figure 1.). Coupled with their lack of natural predators and general tolerance to adverse conditions, this indicates they could be significant contributors to nutrient loading (Wittmann, 2008).

Figure 1: High Density Clam Bed Photo taken from Wittmann, et al. (2008).

Nutrient loading and algal blooms are already consistent problems in Lake Champlain and the introduction of *Corbicula fluminea* would undoubtedly worsen the situation. The Asian clams will have severe impacts on the health of the lake, as large algal blooms result in hypoxic conditions and generally poor water quality for recreational activities (Pinckney et al., 2001).

As the Asian clam filters a large amount of water, they contribute to a decline of phytoplankton and zooplankton communities (Wittman, 2008). This decline in plankton populations could have significant impacts on the native food webs. Plankton are the primary food source for many secondary consumers including several of Lake Champlain's sport fishing species.

Shell material from the clam is commonly found in large quantities deposited on beaches, degrading the aesthetics as well as recreational functionality due to the numerous sharp edges. This leads to fewer people traveling to beaches impacted by the Asian clam, creating a sharp decline in revenue from tourism for the local communities, as well as a direct cost for the beach cleanup and Asian clam eradication efforts. It is speculated that areas of Asian clam infestations would provide an accessible substrate for invasive zebra mussel colonization of previously uninhabitable parts of the lake (Menninger, 2012). This makes the current efforts of combating the Zebra mussel even more difficult.

The Asian clam has already swept across North America invading streams, rivers, canals and lakes as close as Lake George (Modley, 2012). Lake Tahoe now contains a population of *C. fluminea* too large to effectively and economically contain. If preventative measures aren't taken, Lake Champlain could succumb to the same fate as Lake Tahoe.

Aquatic biologists have difficulty predicting how an invasive species will affect an ecosystem that is already experiencing adverse effects from other invasives. The nonnative species that have invaded Lake Champlain threaten native fish and plant species by exhausting existing lake resources. In its current state, the Lake Champlain ecosystem can ill afford another invasive species.

Goal

The goal of this assessment is to evaluate the effects we can expect from a potential Asian clam invasion of Lake Champlain and to assess where prevention and management efforts will be most effective. We will also examine the efficiency of various eradication methods.

Objectives

Our objectives for this assessment are to determine the potential impacts of the arrival of Asian clam in Lake Champlain and to examine possible control methods. This will be done by investigating effects of the invasive clam on water quality, nutrient loading, algal blooms, other organisms from plankton to fish, recreational, and economic activity. We will then establish suggestions for a response framework.

During the Asian clam encroachment on our country's waterways, many methods of eradication have been attempted. These alternatives include the use of a chemical called Bayluscide, diver assisted suction harvesting, heat treatments, the "no action" approach, and the installation of benthic mats **(**LGACRRTF, 2012**).**

Chemical treatment using Bayluscide was found to be ineffective in the laboratory and thus was eliminated as a treatment option (LGACRRTF, 2012). Diver assisted suction harvesting involves sending divers to the lake bottom to remove a layer of sediment from the bottom by way of an aquatic vacuum system. This option was proposed and has been used with moderate success in rocky areas of Lake George where benthic mats could not get a sufficient seal on the lake bed. High costs, ice-out conditions, and logistical issues forced the Lake George Task Force to abandon suction harvesting as an option in favor of additional benthic mats in non-rocky areas.

Heat tests were run on December 6th, 2010 in Lake George to determine the efficiency of heat as a treatment for Asian clams. During these tests, hot water was used in an attempt to kill Asian clams on the surface and in the sediment. This experimental treatment method also failed and thus is not considered to be a viable option for eradication (LGACRRTF, 2012).

Methods and Approach

Our risk assessment is centered around reviewing literature of known Asian clam effects and control measures. We sought data on public access areas, which might serve as invasion foci for the species due to the potential of accidental human assisted introduction. We corresponded with Meg Modley, the Lake Champlain Basin Program Aquatic Nuisance Species Coordinator, about the status of the Asian clam in Lake Champlain and the control measures taken thus far. We spoke with Bill Gill, the government document librarian of the UVM Bailey Howe map room, in an attempt to find Lake Champlain sediment maps to identify potential areas of colonization. It was later determined through correspondence with Ellen Marsden of UVM fisheries program that no such map yet exists.

We can benefit greatly from studying other lake ecosystems that have been affected by the invasion of the Asian clam. The effects of the Asian clam have been studied for a longer period of time in Lake Tahoe, and we can learn much about the Asian clam's production and invasive potential from this example. Lake George is similar enough to Lake Champlain in location and climate, that their Asian clam control tactics may prove to be just as effective in Lake Champlain.

The Lake Champlain Basin Program (LCBP) is a group of agencies from the surrounding area of Lake Champlain. Included in this program are participants from Canada, Vermont, New York and two government agencies; the U.S. Environmental Protection Agency and the New England Interstate Water Pollution Control Commission (LCBP, 2011). The program was created to help protect Lake Champlain from water pollution, protect the wildlife, and support recreational activities in and around the lake. Since invasive species threaten this mission, they have become a focal point for the program. According to the Lake Champlain Basin Program, there are seven non-native species that exist in the lake today and are of high concern or priority.

The Lake Champlain Basin Program has a rapid response program for invasive species such as the Asian clam. The Asian clam was first found in the Lake Champlain Basin in 2010 in Lake George but was speculated to have arrived several years earlier. Since the clam has yet to present itself in the Lake Champlain, the LCBP is managing them as an "aquatic nuisance species" (LCBP, 2012). To understand the Lake Champlain ecosystem and how the LCBP is managing it, we corresponded with Meg Modley, the aquatic nuisance species coordinator. She gave us some insight as to how the LCBP operates and how it would react to the sudden influx of Asian clams.

Findings

The origin of the Asian clam as an invasive species has been traced to introduction on the west coast as a food source (Menninger, 2012). Since its introduction to United States waterways, it has made its way into many of our nation's iconic waters including our neighboring Lake George, but it has not yet been found in Lake Champlain. As such, we have a unique opportunity to learn from other infestations and prepare ourselves to contain an Asian clam invasion, should it occur.

When Asian clam populations establish in an area, they have the ability to filter huge quantities of water: between 67.3-147.7 ml/hour for a medium sized clam (Way, 1988). They also excrete high levels of nitrogen and phosphorus (Wittmann, 2008). These effects compound into declines in plankton populations in the lake from filtration, an increase in algal growth due to the excrement, and stress on other organisms (Wittmann, 2008). The following figure shows the chemical additions of soluble reactive phosphorus (SRP), biologically available Nitrogen in the form of ammonium (NH4), and ammonia (NH3) as well as oxygen uptake rates by *C. fluminea.*

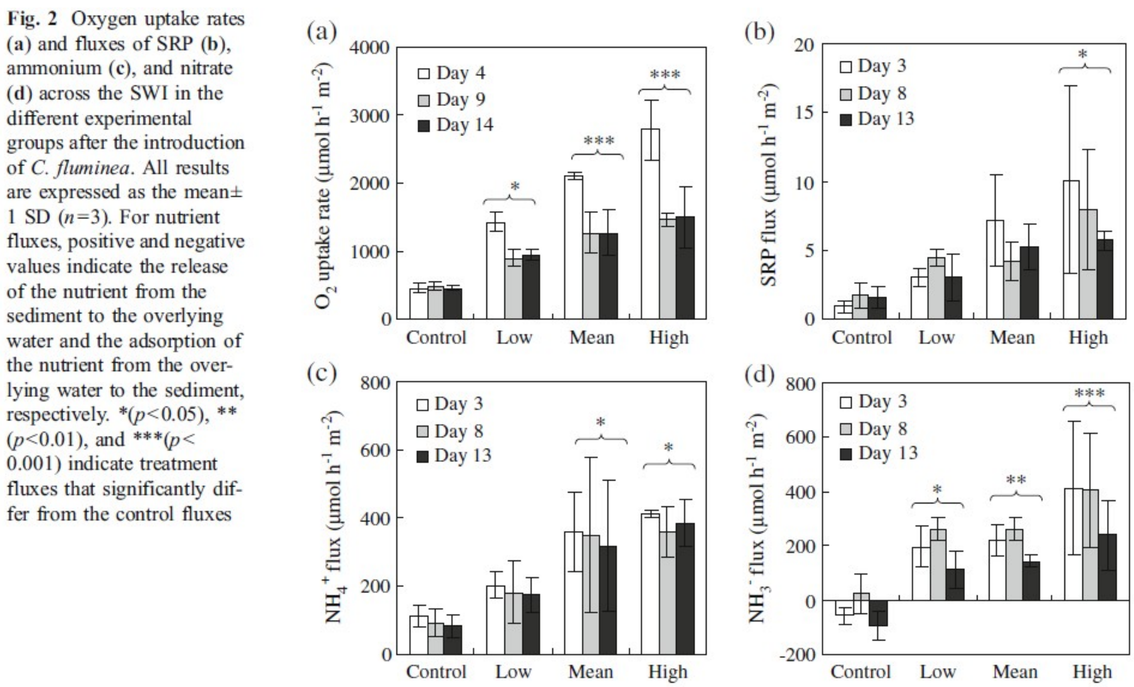

Figure 2: Chemical impacts of Asian clam. taken from Zhang, L., Shen, Q., Hu, H., Shao, S., & Fan, C. (2011).

As indicated in Figure 2, *C. fluminea* has the tendency to excrete large concentrations of ammonia (NH_3^-) into overlying waters. These concentrations of ammonia would be lethal to the freshwater mussels and the native fish species that exist in Lake Champlain today. There are fourteen native freshwater mussel species that exist in Lake Champlain currently, five of which are highly sensitive to fluxes in ammonia concentration. These species include the *Lasmigona costata* (fluted shell), *Lampsilis cardium* (pocketbook mussel), *Pyganodon cataracta* (eastern floater), *Pyganodon grandis* (giant floater), and the *Lampsilis radiata* (eastern lampmussel) (Davis, 2008). The sensitivities of these can be seen in Chart 1.

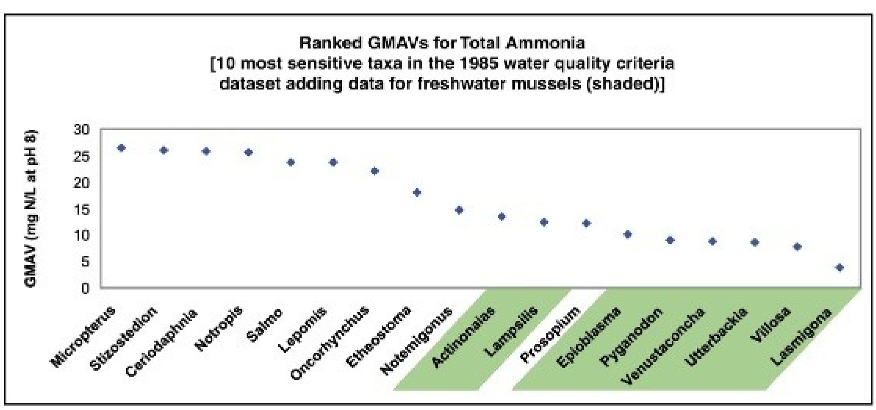

Chart1: Sensitive aquatic genera to ammonia including freshwater mussel taxa. Taxa that exist in Lake Champlain are **Lampsilis, Pyganodon, and Lasmigona**. (Davis, 2008) GMAV is an acronym for Genus Mean Acute Values. If data from several species in a single genus are available, the Species Mean Acute Values are pooled to calculate a geometric mean of the genus toxic concentration (Davis, 2008).

There are eighty-one species of fish that have been identified in the Lake Champlain Basin, twenty of which are prized by anglers (LCBP, 2011). The native fish species in the Lake Champlain basin would also be adversely affected by the amount of ammonia that is secreted by *C. fluminea*. Chronic exposure to ammonia has detrimental effects on gills and other tissues, leaving fish susceptible to bacterial infections, and can stunt the growth of juveniles (Francis-Floyd et al., 2005). High enough doses of ammonia are lethal for fish species.

In heavy densities, *C. fluminea* can cause dissolved oxygen levels in the water to drop below 1.0 mg/L (Cherry et al., 2005). At this level of dissolved oxygen, fish life cannot be supported and even the *C. fluminea* begin to die off in large quantities.

As previously seen in Figure 2, the Asian clam secretes biologically available Nitrogen and Phosphorus into the surrounding environment. Chart 2 demonstrates the amount of these nutrients a single clam can produce based on its shell size.

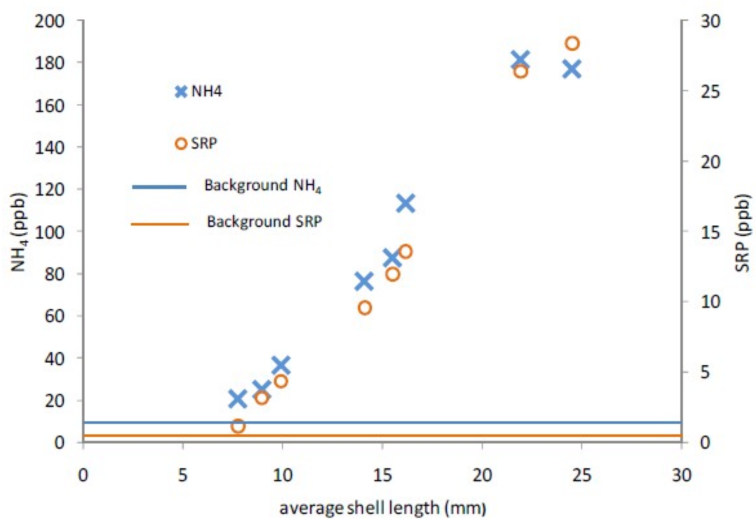

Chart 2. Asian Clam nutrient excretions by individual shell size vs background nutrient levels (Wittmann, 2008)

The effects of these excretions on the Phytoplankton and therefore algal communities can be determined by the corresponding chlorophyll levels as seen in in Chart 3.

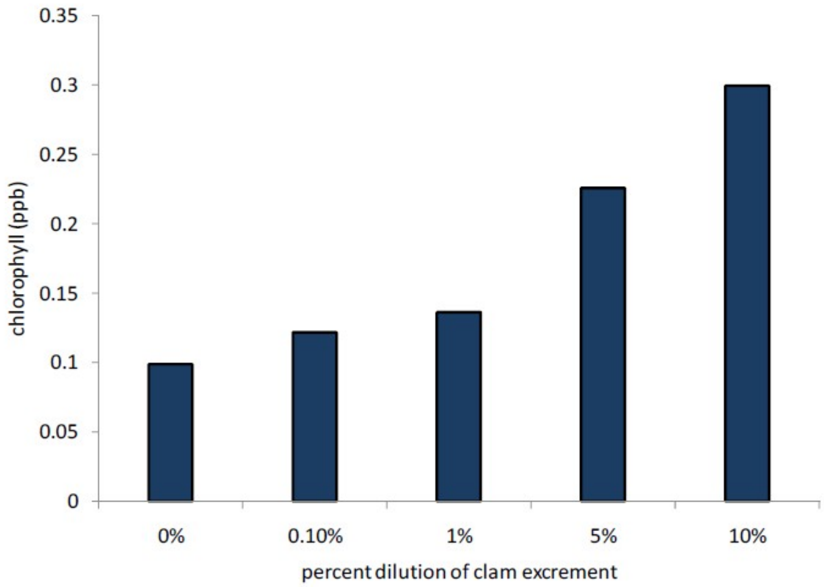

Chart 2. Effects of nutrient excretions on phytoplankton and therefore algal densities by measurable chlorophyll levels (Wittmann, 2008)

The additional nutrient loading from the clams can worsen the effects of nuisance algal blooms including the poisonous blue green algae species. The areas of Lake Champlain that are most affected by current poisonous blooms are indicated in Figure 3.

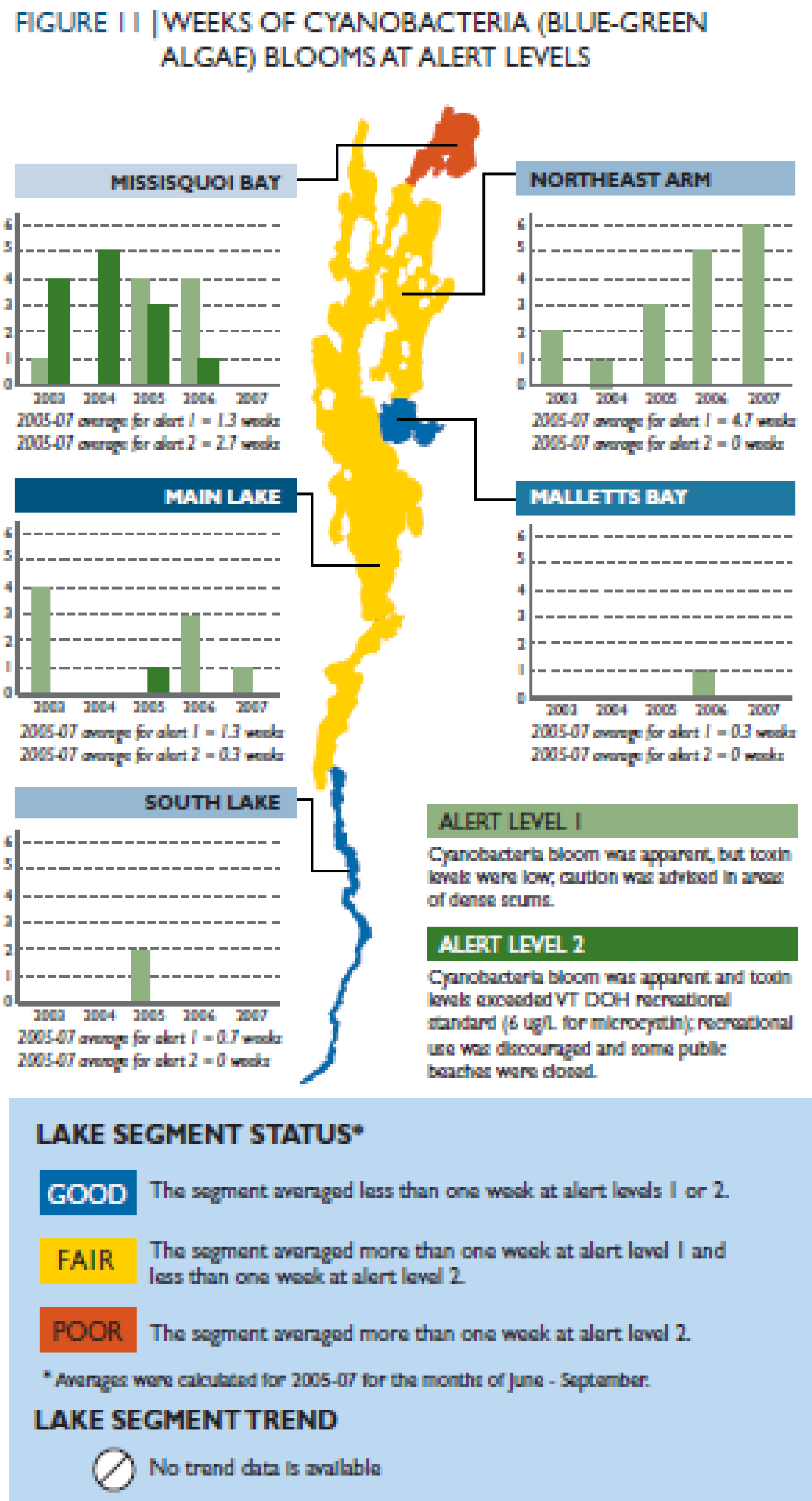

Figure 3: Algal Blooms in the Lake Photo taken from "State of the Lake an Ecosystem Indicators Report." (2008)

Delaying action upon the Asian Clam’s arrival would be a huge mistake. If a population is detected early enough, it can be eradicated effectively through benthic mats (LGACRRTF, 2012). If we take no action to prevent them from spreading, the clams will aggravate algal problems, stress populations of phytoplankton and zooplankton as well as the species that rely on them, as illustrated in Figure 4. Ultimately this invasive species will negatively impact fishing, swimming, and other tourist activities that bring economic activity to lake communities.

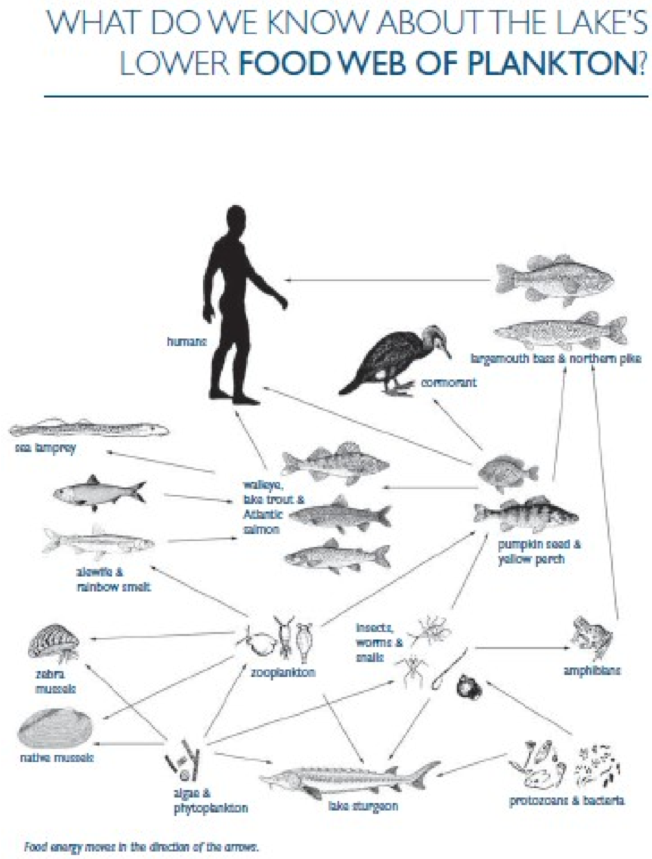

Figure 4: Illustration of plankton-reliant species
Photo taken from "State of the Lake an Ecosystem Indicators Report." (2008)

C. fluminea is a filter feeding organism that has the potential to out compete the native species for resources. *C. fluminea* reproduce, and filter water at higher rates than native mussel species leaving them outnumbered and without the resources they need to survive. Competition for resources will occur between native fish species and *C. fluminea* in an indirect way. The high rate at which *C. fluminea* filter phytoplankton causes the population of zooplankton to plummet. This causes the population of small feeder fish to drop, as well as the larger fish that feed on them.

With plummeting fish populations, recreation in Lake Champlain is bound to decline. Native fish species of Lake Champlain that are sought by anglers include large and small mouth bass, walleye, northern pike, chain pickerel, brown bullhead, channel catfish, yellow perch, lake trout, landlocked Atlantic salmon, steelhead trout, brown trout, and rainbow smelt. (LCBP, 2011). These anglers fishing Lake Champlain spent $205 million in a year just on fishing goods (Lake Champlain International, 2010). When the population of these popular native fish species begin to drop due to the presence of *C. fluminea*, anglers will bring their money elsewhere and Vermont's revenue from tourism will decline immensely. Given these statistics, we can ill afford to ignore the threat to the lake.

Preventing the Asian clam from entering the lake is a near impossible venture due to the sheer number of vectors for introduction. The Asian clam could make its way to Lake Champlain actively through canals, or as passengers on anything from boats, to imported sand, to bait buckets (LGACRRTF, 2012). The best approach we have found to prevent the human assisted spread of the Asian clam is the education of the public at recreational hot spots. We consulted the map, included below as Figure 5, to determine which areas should receive the most preventative attention and resources around the Lake. Marinas, boat launches, and beach areas pose the threat of unintentional bait or equipment introductions in addition to being in close proximity to Asian clam habitat.

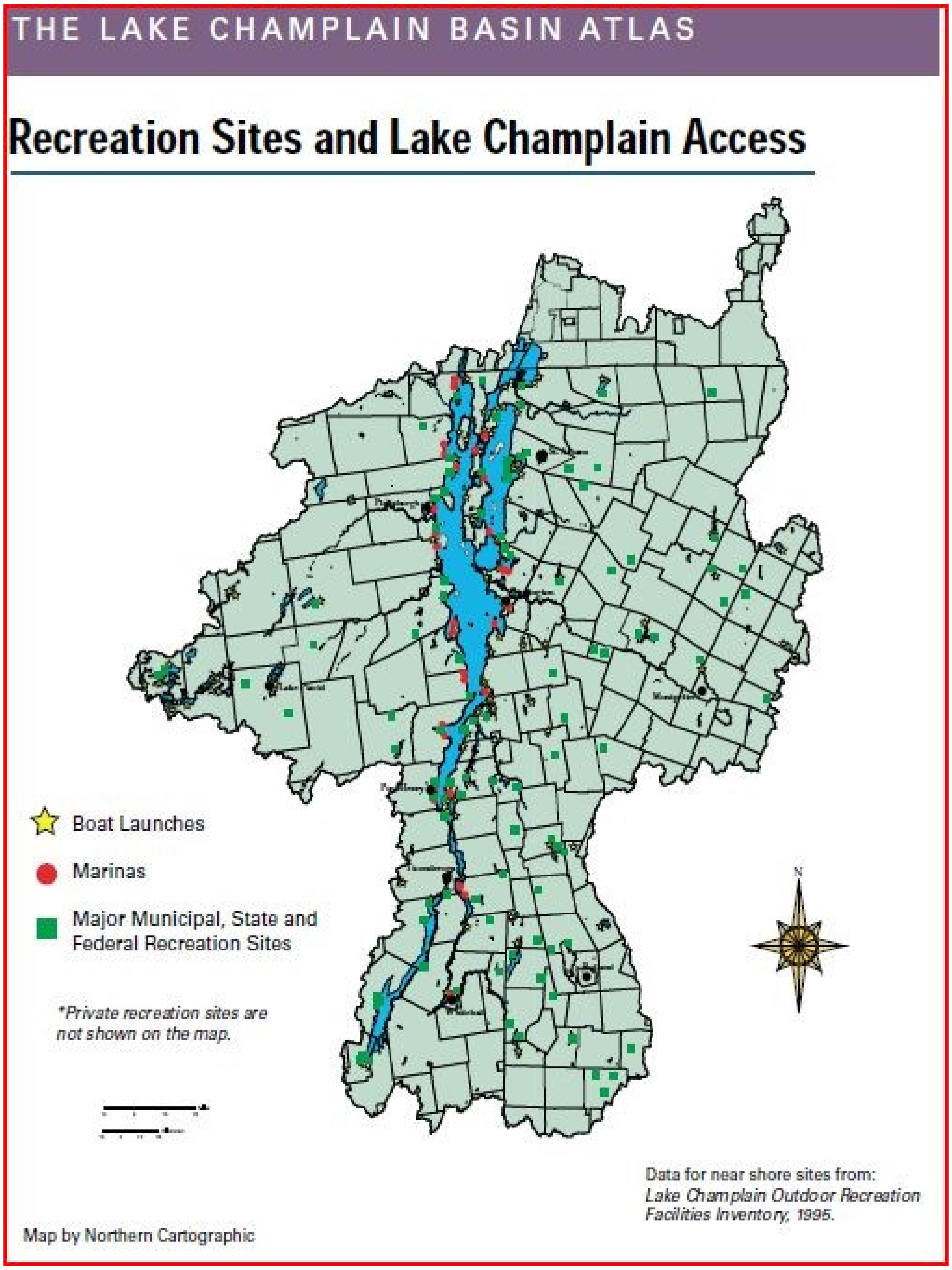

Figure 5: Public Access points for prevention focus around Lake Champlain.
Image provided by Meg Modley from the Lake Champlain Basin Atlas (1995)

Discussion/ Recommendations

Thus far, we have examined the effects Asian clams have had on invaded ecosystems and the economies that rely on them. We now undertake an analysis of containment techniques to determine effective measures for Lake Champlain. We hope to find an eradication or containment procedure that will be cost-effective and successful.

Methods of treatment involving chemicals and heat were tested, but both were found to be ineffective in lab and field settings. These two options also have negative impacts on the entire ecosystem. Diver assisted suction was found to be a more effective treatment in areas where benthic mats cannot form an airtight seal. Problems with suction harvest include questionable effectiveness as seen in Table 1, inability to treat due to ice, and high economic costs as depicted in Table 2. These problems are significant enough to deter interest in this approach (LGACRRTF, 2012).

Suction Treatment

Pre Treatment	Post Treatment
135 Samples Taken	105 Samples taken
560 Recovered Inviduals	338 Recovered Individuals
30% Alive	3% Live
6% Dead	8% Dead
64% of samples had no clams	41% of samples had no clams
	48% inactive

Table 1: Effectiveness of suction harvesting had mixed results and may have actually spread the range of the clams when recovered sediments were re-deposited in the lake. Inactive clams were ones that were unable to be declared definitively as alive or dead at the time of treatment (LGACRRTF, 2012).

2011 Expenses	Amount
Materials: Steel	$47,225.02
Materials: Benthic Barrier	$57,489.60
Installation Village-1	$51,231.16
Maintenance Village-1	$58,002.29
Scientific Services	$126,680.00
Mat Removal Village-1	$60,545.41
Reprocessing	$13,569.35
Installation Village-2/Norowal	$34,507.70
Maintenance Village-2/Norowal	$22,200.00
Mat Removal Village-2/Norowal	$19,542.69
Permitting Expenses	$2,533.02
Communication	$1,483.98
Miscellaneous	$620.00
Lake Wide Survey	$21,600.00
Suction Harvesting	$84,528.88
Educational Materials	$2,624.00
Project Assessment	$9,800.00
Archeology (Boon Bay)	$7,000.00
TOTAL	$620,183.09*

2011 Revenues	Amount
NYS Lake George Park Commission	$208,848.00
Warren County	$130,000.00
NYS Dept. of Environ. Conservation	$75,000.00
Lake Champlain Basin Program	$75,000.00
FUND for Lake George	$30,000.00
Lake George Association	$30,000.00
NYS Department of State	$30,000.00
Adirondack Park Invasive Plan Program	$10,000.00
Town of Bolton	$10,000.00
Town of Hague	$5,000.00
Town of Lake George	$5,000.00
Town of Queensbury	$5,000.00
Village of Lake George	$5,000.00
Washington County	$5,000.00
Town of Dresden	$3,000.00
Town of Putnam	$3,000.00
Town of Ticonderoga	$3,000.00
Essex County	$2,500.00
TOTAL	$635,348.00

Table 2: Lake George 2011 expenditures and revenues for clam containment. (LGACRRTF, 2012): Note the high relative cost of suction harvesting, as well as the total cost coverage from allocated funds from federal, state, and municipal sources.

The no action approach has had mixed results. If we take no action, it is possible that even a cold winter could effectively wipe them out . This is a thin branch to hang on to given that climate change projections predict a significantly warmer climate for the Lake Champlain Basin, and the lake has frozen over noticeably less in recent years (NOAA, n.d). Additionally, even if one clam invasion was unsuccessful, the risk of recolonization is too high to rely on harsh winters as a control mechanism by itself.

In the case example of Potomac River Estuary near Washington, DC. Phytoplankton was reduced by 40-60% in areas of highest *C. fluminea* concentrations. A tripling of water clarity was reported in areas of Asian clam beds, and submerged vegetation that had been absent for nearly 50 years had returned. Fishery surveys reported a vegetation increase of 7 fold. In 1986 the Asian clam population was 25% smaller than in 1984. In 1992 the population was 25% smaller than in 1986. However, algal blooms which had been absent in the early 80's, reappeared in 1993. This is interesting as they were not present during the introduction or the peak of the Asian clam boom, but recurred once the clams were in decline. The authors believe the Asian clam triggered the changes in biota over this period (Lake George Asian Clam Eradication Project, 2012). This study was performed on a river, which could yield different the results than a lake would due to the highly mobile water and differences in ecosystem dynamics. Regardless, it is an option with anomalous results that should be further investigated.

Benthic mats have been used successfully in Lake George to deal with Asian clam and Eurasian water milfoil. The process involves laying 20mm thick impervious PVC barriers over the affected areas. The mats overlap and smother the everything under them by reducing the oxygen concentrations below necessary levels for survival. The mats are generally left in place for a period of 4-6 weeks, although they are sometimes left in place longer (Lake George Asian Clam Eradication Project, 2012). This is considered the most effective option for treatment of the Asian clam.

As sandy and gravelly patches are the preferred substrate of the Asian Clams, considering these areas to be at the highest risk for infestation would be wise. A map of lake bottom sediments would be helpful in predicting where Asian clam populations would likely establish themselves. While we didn't have any success finding a map of this type, Pat Manley, a professor of geology at Middlebury college, is currently working on such a map scheduled to be completed sometime in 2017.

As we learned from Lake George and Lake Tahoe, the best way to combat the Asian clam is through prevention. This is accomplished by educating the public and spreading awareness of vectors of Asian clam introduction. The Lake Champlain Basin Program does an adequate job of this already, however, we would recommend widening the scope to include tourism hot spots such as the Burlington waterfront/bike path. We would further recommend collecting funds from groups with an interest in Asian clam to cover the costs of containment efforts.

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